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FIRE HISTORY OF GLACIER NATIONAL PARK:

HUDSON BAY DRAINAGE

Final Report

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INTRODUCTION

Research on presettlement fire regimes is important for managing natural areas such as national parks and wilderness (Kilgore 1981, Arno and Brown 1989, Mutch 1994, Mutch et al. 1994). For example, fire history serves as a critical baseline reference for ecosystem monitoring and restoration, prescribed fire planning, and other management activities. In 1982, long-term studies were initiated to document the fire history of the Waterton-Glacier Ecosystem, which is an International Peace Park and World Biosphere Reserve. Study objectives were to determine presettlement fire history and fire regimes, develop stand origin (fire history) maps, and interpret the effects of attempted fire exclusion after 1900. To date, fire history has been reported for Glacier National Park (GNP) west of the Continental Divide (Barrett et al. 1991), for the Missouri River drainage in southeastern GNP (Barrett 1993), and for adjacent Waterton Lakes National Park (WLNP) in Alberta (Barrett 1996). As the culmination of the long-term sampling, this report describes the fire history of the Hudson Bay drainage in northeastern GNP. The latter three study areas lie on the east side of the Continental Divide, and are contiguous.

Together, the fire history maps generated by all six of these research projects cover the entire Waterton-Glacier Ecosystem, some 458,000 contiguous hectares. Consequently, as the largest fire history study ever done, the results provide unprecedented perspective on fire's role in the diverse ecosystems on both sides of the northern Continental Divide.

STUDY AREA

The 118,239 ha. study area in the Hudson Bay drainage ranges from 1279 to 3190 m. in elevation (fig. 1). The area occurs in a major transition zone between Northern Rocky Mountain- and Northern Great Plains ecosystems. Intersecting and sharply contrasting Continental- and Pacific Maritime climatic regimes (Finklin 1986), along with abrupt topographic relief, promote dramatic shifts in vegetation over a very short lateral distance (Arno 1979). Beginning at the Rocky Mountain Front, fescue (*Festuca* spp.)-dominated meadows and climax aspen (*Populus tremuloides*) groves adjoin a comparatively narrow band of montane- and subalpine forests ascending into alpine rocklands (Lynch 1955, Arno 1979). Coniferous forests occupy about one-third of the study area, along with herbaceous communities (13%), aspen groves and associated shrublands (6%), and alpine rocklands and water bodies (48%)(fig. 2). Short-stature, wind-stunted stands in the continuous forest near the mountain front are dominated by seral Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and/or lodgepole pine (*Pinus contorta*), and dry rocky sites are often occupied by climax limber pine (*Pinus flexilis*). Low elevation forest habitat types (Pfister et al. 1977) are usually in the subalpine fir (*Abies lasiocarpa*) or spruce (*Picea engelmannii* X *glauca*) series. For example, habitat types on relatively dry sites often key to subalpine fir/dwarf huckleberry (*Vaccinium caespitosum*) or /twinlineflower (*Linnaea borealis*), whereas moist stands often key to subalpine fir- or spruce/queencup beadlily (*Clintonia uniflora*) or /grouse whortleberry (*V. Scoparium*). The upper subalpine forest is dominated by various admixtures of seral lodgepole pine, whitebark pine (*Pinus albicaulis*), and spruce-fir. Here, moderately dry sites often are in the various phases

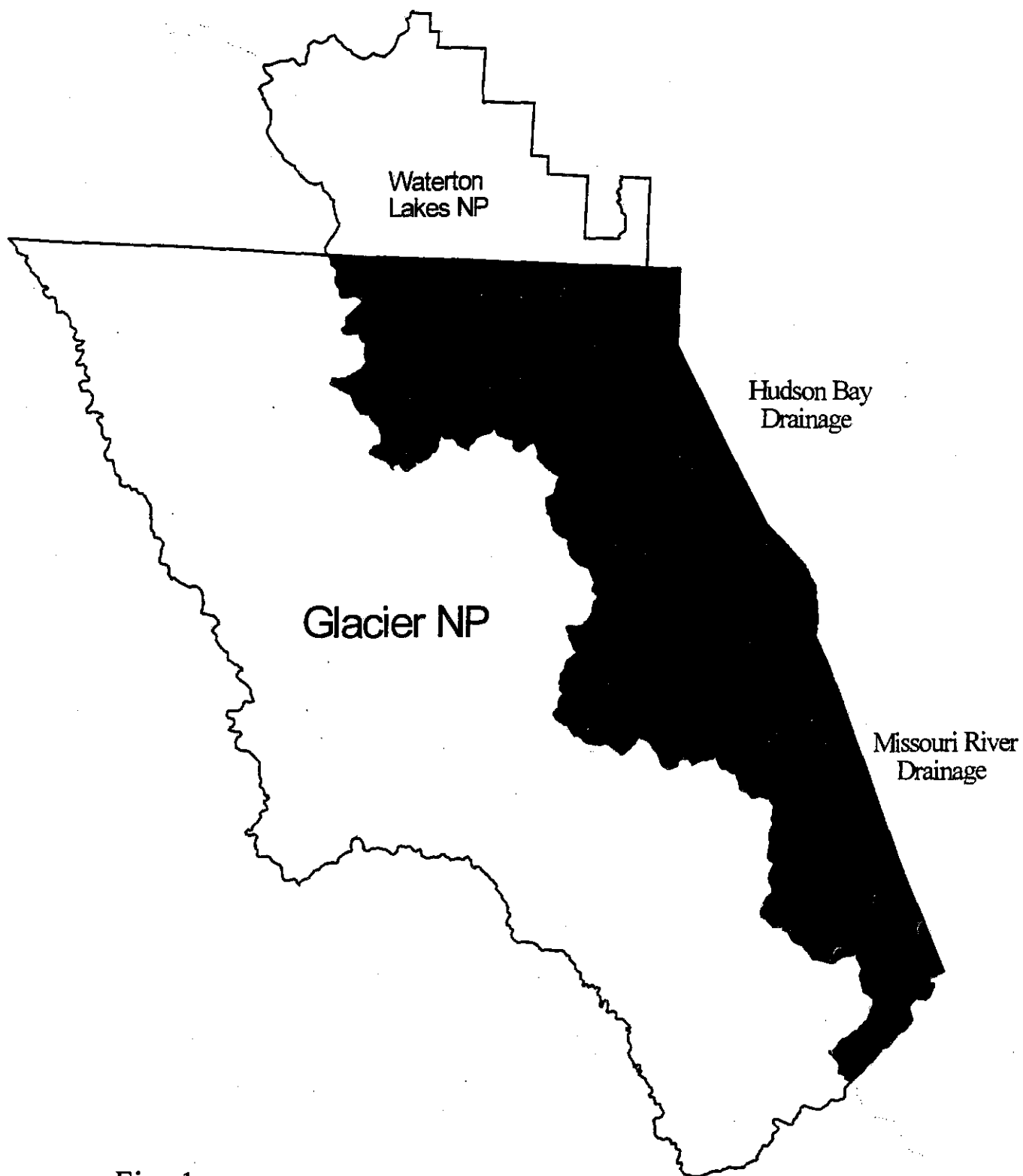


Fig. 1

**Waterton-Glacier
International Peace Park**

Scale 1:500,000



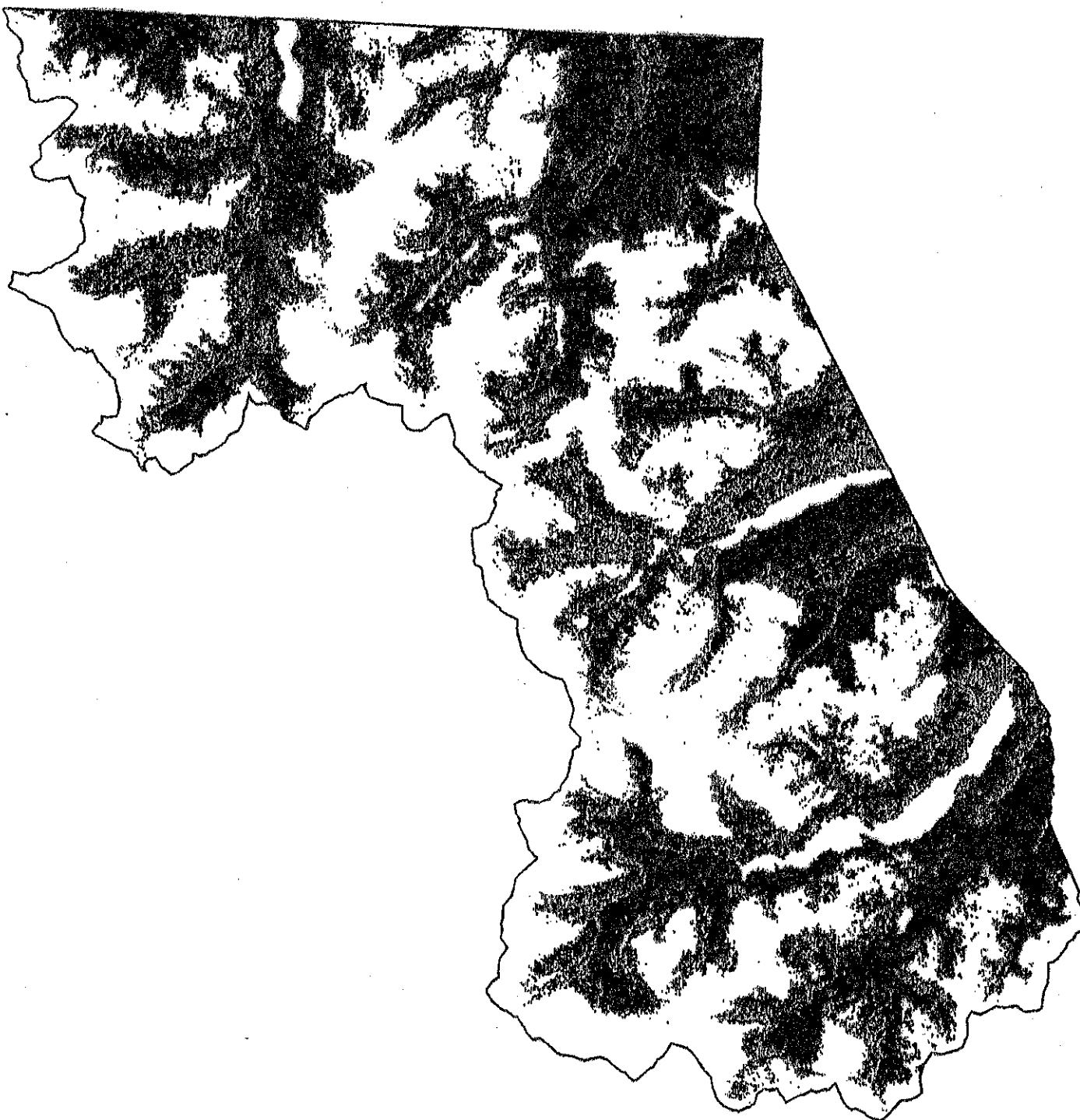


Fig. 2

- Herbaceous (13%)
- Conifer Forest (33%)
- Deciduous tree/shrub (6%)
- Water/non-vegetated (48%)

Landcover - Hudson Bay Drainage

Scale 1:270,000

of subalpine fir/beargrass (*Xerophyllum tenax*) or subalpine fir-whitebark pine/grouse whortleberry, and moist sites usually key to subalpine fir/huckleberry (*V. globulare*) or /menziesia (*Menziesia ferruginea*) habitat types. South-facing stands at upper timberline are usually dominated by climax whitebark pine (whitebark pine/subalpine fir h.t.), whereas highly scattered stands dominated by alpine larch (*Larix lyallii*) occur on northerly aspects (i.e., alpine larch/subalpine fir h.t.)(Arno and Hoff 1989, Arno 1990).

METHODS

Fire history was documented by sampling fire-initiated age classes and tree fire scars along transects on representative terrain (Arno and Sneek 1977, Barrett and Arno 1988). To avoid damaging trees, the fire scars were sampled by increment boring (Barrett and Arno 1988) rather than by sawing (Arno and Sneek 1977). Also, the years and locations of post-1900 fires were documented by consulting the park fire atlas (on file, GNP Archives). After sample preparation and analysis, the estimated fire scar- and stand initiation years were compiled into master fire chronologies (Romme 1980) for the entire study area and for representative stands (Romme 1980, Arno and Peterson 1983). A stand origin map reflecting the area fire history (Heinselman 1973) was developed by cross-referencing the site data to stand polygons visible on 1968 series aerial photographs. After completion, the map was forwarded to the GNP Research Division for GIS digitizing, enabling an analysis of fire history statistics at the landscape scale.

For the stand scale of analysis, fire regimes (Agee 1993) and post-fire succession were interpreted by analyzing stand fire history relative to tree species coverage in representative circular macroplots (.04 ha.; Pfister et al. 1977). Stand fire frequency was estimated from fire

scars and by using age class chronologies (Barrett and Arno 1988), which are based on pith samples from fire-killed snags and remnant survivors.

RESULTS

Study Area Fire Frequency. Sampling at 214 sites produced 843 increment cores from the area's fire-initiated age classes, primarily lodgepole pine and Douglas-fir. Fire scarred trees generally were scarce, but 60 scar samples were also obtained. Most scarred trees had one scar, but a few old Douglas-firs had up to four scars each. The scarcity of scarred trees indicates that the stand replacement fire regime (Agee 1993) predominates in the study area, agreeing with results from the previous east-side study areas (Barrett 1993, Barrett 1996). Scarred trees usually indicated a burn margin effect (Romme 1982), that is, heavily scorched survivors at the margins of stand replacing runs, rather than widespread underburning (Barrett et al. 1991, Agee 1993, Barrett 1994, Brown et al. 1994). In fact, the stand origin map (on file, GNP Research Div.) indicates that less than 10 percent of the stands in the seral age class mosaic are multi-aged (i.e., seral component) as a result of mixed severity fire. These stands usually occur near meadows, on valley-bottom benches and sparsely forested south-facing slopes, and occasionally along upper timberline. However, even the driest stands contain few Douglas-firs older than 300 years, reflecting the area's history of relatively severe fires.

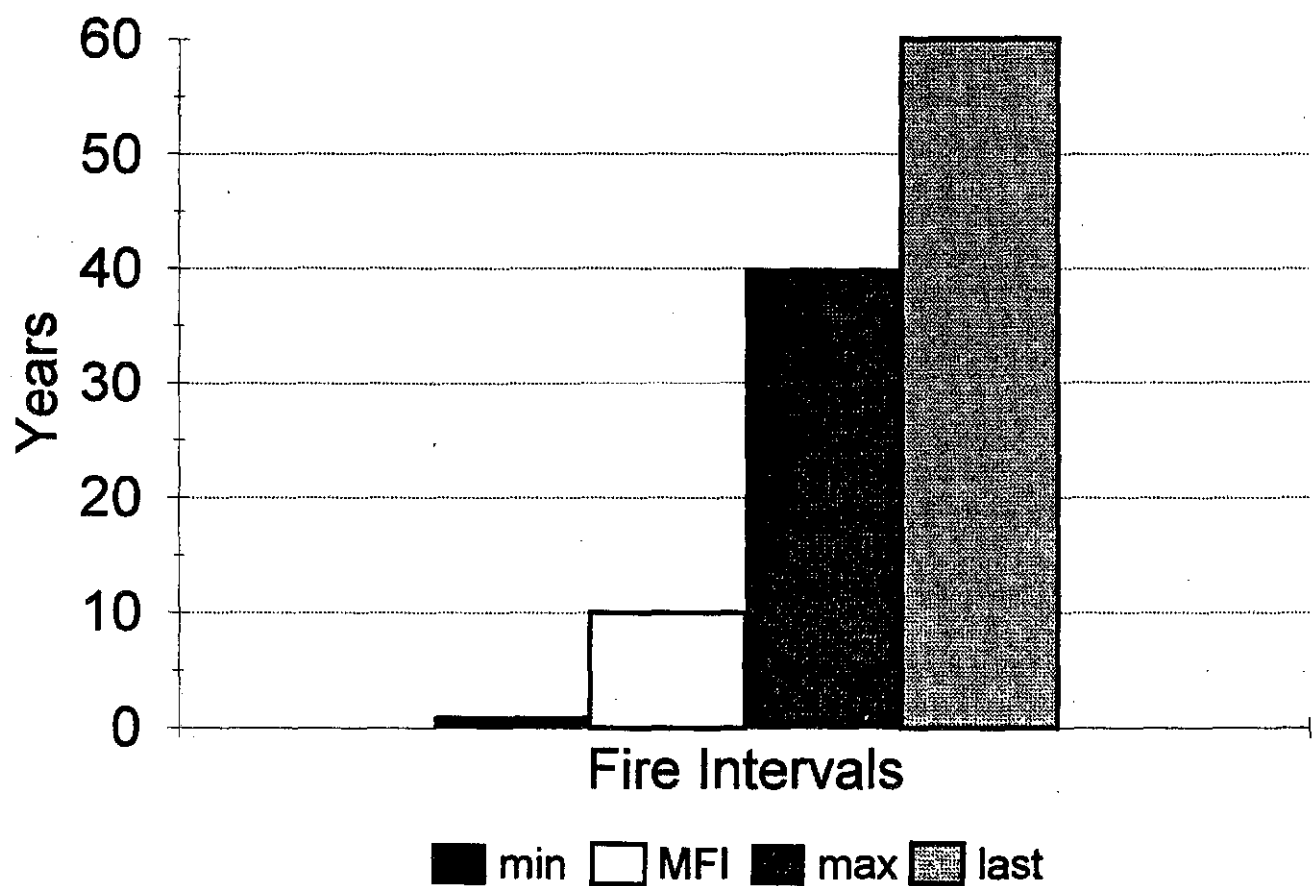
The earliest fire dates from ca. 1488, based on pith dates from remnant western larch (*L. occidentalis*) in the lower Rose Creek drainage, near Rising Sun. However, the most sequential portion of the fire chronology evidently spans from 1726 to 1936, during which about 98 percent of today's seral stands regenerated. The chronology (Appendix) contains an estimated 23 fires

between 1726 and 1936, which was the last fire year of any consequence in the study area. Fire intervals during this period ranged from one to 40 years long, and the area mean fire interval (MFI) was 10 years. That is, on average, a spreading fire occurred somewhere in the 118,000 ha. study area about every 10 years between 1726 and 1936. Furthermore, when including data from remnant old age classes no longer mappable, the chronology is relatively sequential back to ca. 1561. For example, the post-1561 fire intervals range from one to 46 years long, and the area MFI is 13 years. Therefore, study area fire frequency has been consistently high throughout most of the last four centuries. By comparison, today's 60 year long fire interval is unprecedented, and six times longer than the post-1726 MFI (fig. 3).

Fires were even more frequent in the previous east-side study areas, namely, in GNP's 33,000 ha. Missouri River drainage (Barrett 1993) and in 50,000 ha. WLNP (Barrett 1996). MFIs for similar time periods were four and three years, respectively, when proportionalized by land area. Those smaller study areas contain relatively more terrain along the mountain front, where mixed severity fires were common. However, the last fires in those areas occurred in 1919 and 1935, respectively.

The stand origin map also provides useful information on area fire occurrence. For example, fire cycles can be calculated based on the estimated amount of area that burned during each century in the chronology (figs. 4, 5). Fire cycle is the time required to burn an area equal in size to the entire study area (Romme 1980). At least seven fires occurred during the 1700s, producing about half of today's seral stands. At that rate, therefore, an area equal to the entire study area would have burned in 200 years. This estimate is undoubtedly conservative because subsequent fires destroyed some 1700s-regenerated stands. Dendro-climatological

Fig. 3. Study Area Fire Intervals
1726-1996



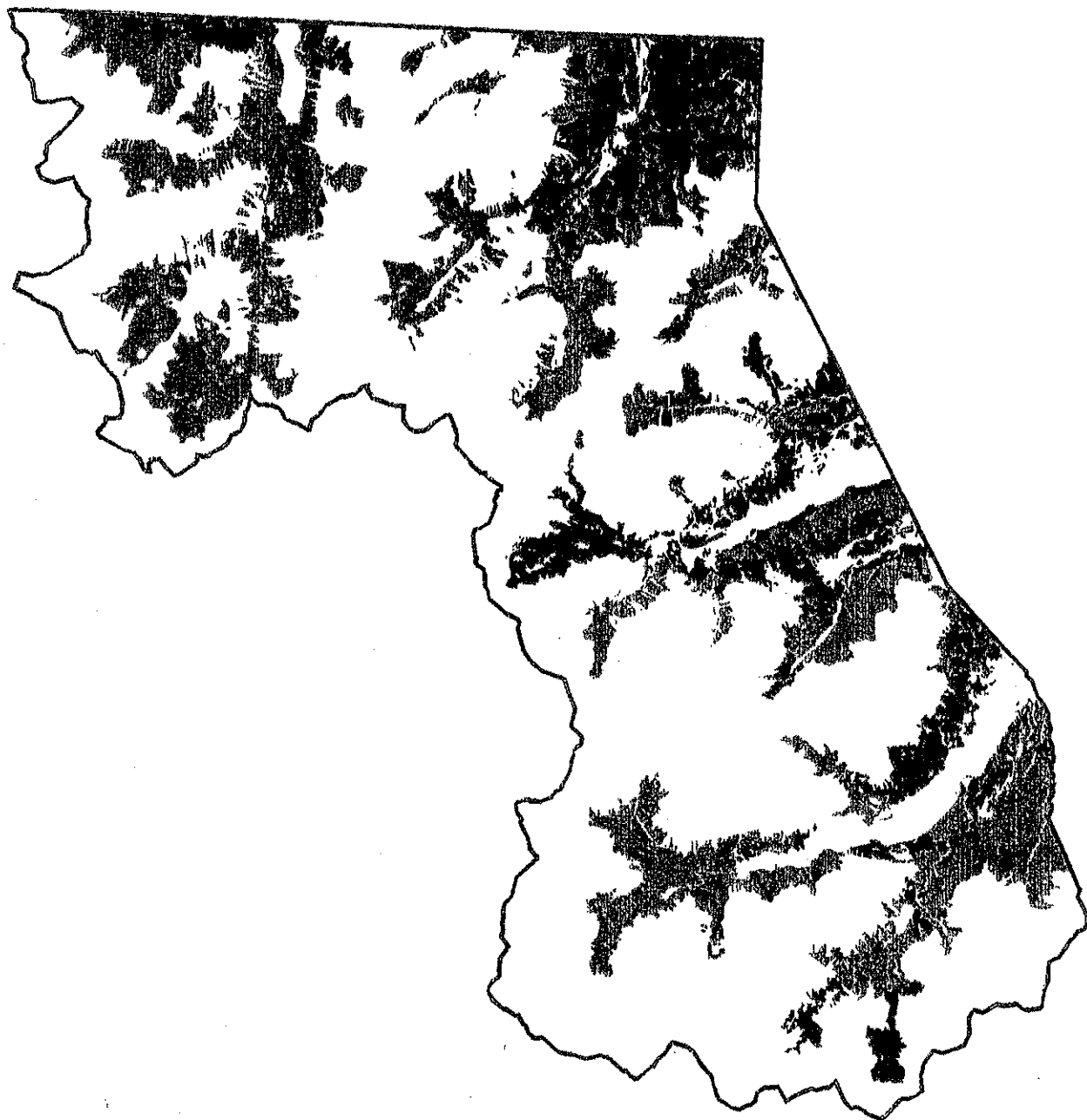





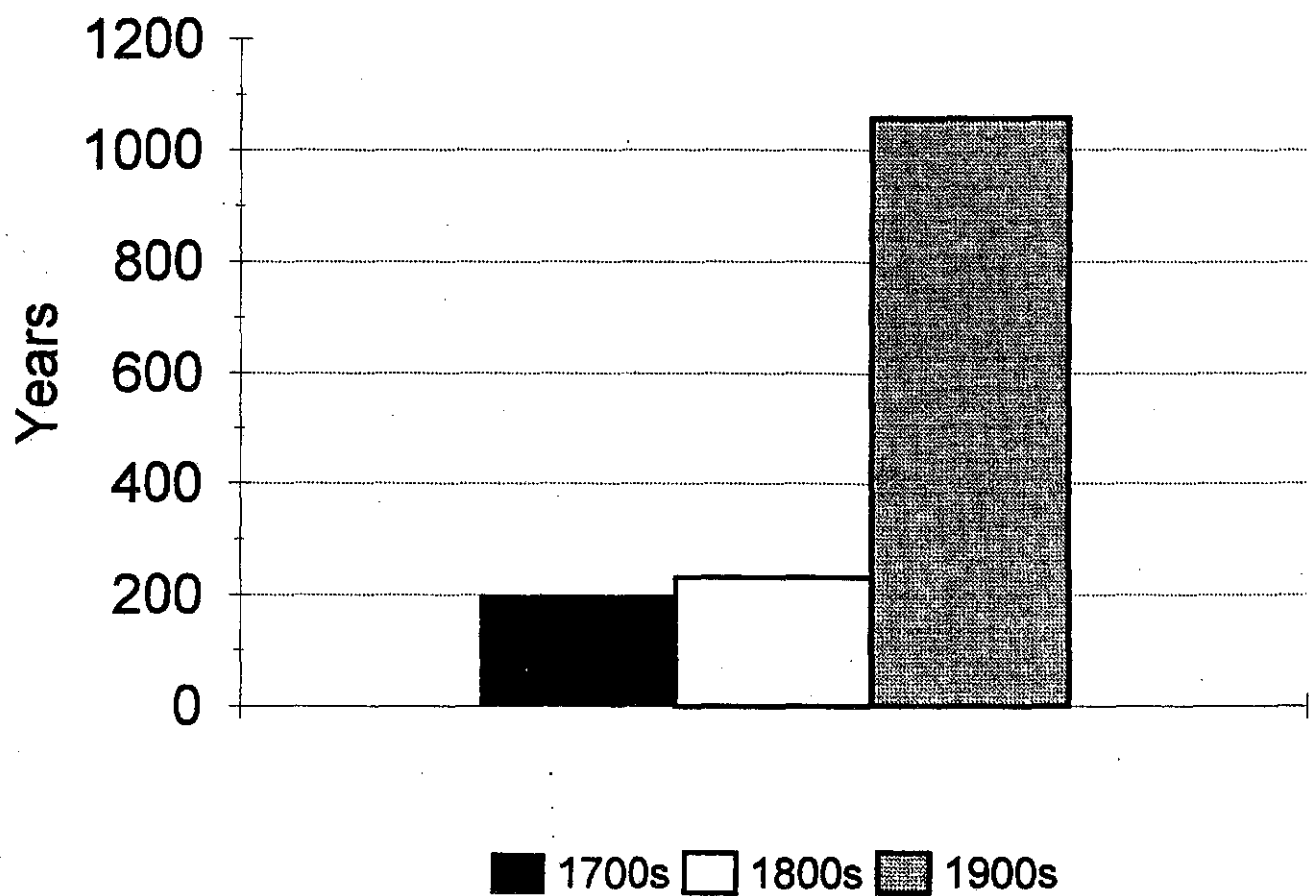
Fig. 4

-  1700's regeneration
-  1800's regeneration
-  1900's regeneration

Fire Regeneration by Century

Scale 1:270,000

Fig. 5. Fire Cycles by Century



investigations in the general region (Graumlich 1987, Meko et al. 1993), fire history studies elsewhere in Waterton-Glacier (Barrett et al. 1991, Barrett 1993, Barrett 1996), and coarse-scale fire frequency for the Columbia River Basin (Barrett et al. [in press]) verify that many drought episodes and concurrent large fires occurred during the 1700s. For example, extensive stand replacement burning also occurred on GNP's west side (Barrett et al. 1991), as well as throughout much of Yellowstone National Park (Romme and Despain 1989, Barrett 1994). During the 1800s, an estimated ten fires produced 39 percent of today's seral stands. Fire cycle for the 19th century was thus 256 years, also likely conservative because of later stand replacing fires. Burned area thus may have decreased only slightly during that century, the early- to mid portion of which represents the peak of the cool-moist "Little Ice Age" (Carrera and McGimsey 1981). Subsequently, as elsewhere in the Northwest, drought enhanced wildfires burned many areas in Waterton-Glacier between the late 1800s and early 1900s (O'Brien 1969, Barrett et al. 1991, Barrett 1993, Barrett 1996, Barrett et al. [in press]). Although droughts have remained commonplace, fire frequency for the 20th century declined sharply. Six fires occurred between 1900 and 1936, producing just 9 percent of today's seral stands, followed by the current 60-year long fire-free interval. Fire cycle for the 20th century to date is 1056 years, a four- to fivefold decrease in burned area when compared with the previous two centuries (fig. 5). These findings, and those from the two adjacent east-side study areas, clearly implicate effective fire suppression at the landscape scale (discussed below).

Stand Fire Regimes. The fire history data were also analyzed for the stand scale (Arno and Peterson 1983) to determine presettlement fire regimes for the various cover types. Such data are useful for monitoring stand successional trends, identifying potentially shifting fire

regimes, and prescribed fire planning (Arno and Brown 1989, Mutch 1994, Mutch et al. 1994, Quigley et al. 1996). For instance, knowing the mix of past fire regimes and current successional trends allows managers to delineate zones for continued total fire suppression, or for planned and unplanned prescribed fires. The stand origin map (on file, GNP Research Div.) can also be used in identifying specific drainages and stands with potentially disrupted fire cycles, which is useful for scheduling prescribed fires.

Representative data were obtained from 15 comparatively dry stands in the montane- and lower subalpine forests (table 1, fig. 6). Such stands occupy about 10 percent of the seral forest mosaic, often in a narrow ecotone between prairie grasslands and moist subalpine forests in the mountain canyons (fig. 7). Dry sites dominated by Douglas-fir and/or lodgepole pine often support multiple even-age classes with scattered fire-scarred veterans, particularly near meadows. This suggests a pattern of mixed severity fires (Arno 1980, Parker 1982, Barrett et al. 1991, Agee 1993, Arno et al. 1993, Brown et al. 1994, Barrett 1995, Quigley et al. 1996), ranging from light underburns along meadow edges to largely lethal fires on steeper forested terrain. Fire frequency also displayed wide variation. Pre-1940 stand MFIs ranged from 21 to 92 years long, and the 15-stand mean was 48 years. By comparison, the current fire intervals range from 60 to 231 years long, and the 15-stand mean is 131 years. The latter integer is about twice as long as the mean maximum interval found for the pre-1940 period (i.e., 71 yr), and nearly three times longer than the mean MFI of 48 years. Therefore, effective fire suppression evidently has precluded from one to four mixed severity fires from any given stand near lower timberline, strikingly similar to results from the previous east-side study areas (Barrett 1993, Barrett 1996).

Table 1. Fire frequency data from 15 representative stands in the mixed severity fire regime.

Plot No ¹	Cov. Type ²	Hab. Type ³	Asp	Elev. (m)	MFC ⁴	No. Fires	Intvl. Range (yr)	MTI ⁵ (yr)	Last Fire ⁶ (yr)
13	DF-LP	A/Xete	SW	1469	1751-1844	3	14-79	47	152
29	LP-DF	A/Clun	S	1448	1751-1794	2	43	-	202
30	L-DF	A/Clun	E	1457	1732-1794	4	14-19	21	202
32	DF-LP	A/Clun	SE	1378	1765-1910	4	19-101	48	86
34	DF-LP	A/Clun	SE	1433	1765-1910	5	19-69	36	86
37	LP-DF	A/Clun	E	1427	1866-1910	3	19-25	44	86
44	DF-LP	A/Arco	SE	1792	1765-1891	4	24-77	42	105
49	DF-LP	A/Clun	W	1585	1488-1765	4	33-171	92	231
51	DF	A/Caru	NW	1390	1561-1794	5	29-138	58	202
52	DF	A/Caru	NW	1402	1732-1936	4	56-86	68	60
53	DF	A/Caru	W	1402	1765-1880	4	29-50	38	116
70	DF-LP	A/Clun	W	1427	1732-1844	3	50-62	56	152
95	LP	A/Xete	S	1683	1834-1889	3	20-35	28	107
98	LP	A/Vagl	S	1597	1794-1921	4	35-52	42	75
207	DF	A/Clun	W	1311	1794-1889	3	34-61	48	107
<hr/>									
Range: 1311-1792					1561-1936	2-5	14-171	21-92	75-231
Mean: 1480					-	-	29-71	48	131

1. Locations on stand age class map (on file, GNP Research Div.).

2. LP=lodgepole pine DF=Douglas-fir SF=spruce-fir WB=whitebark pine L=western larch

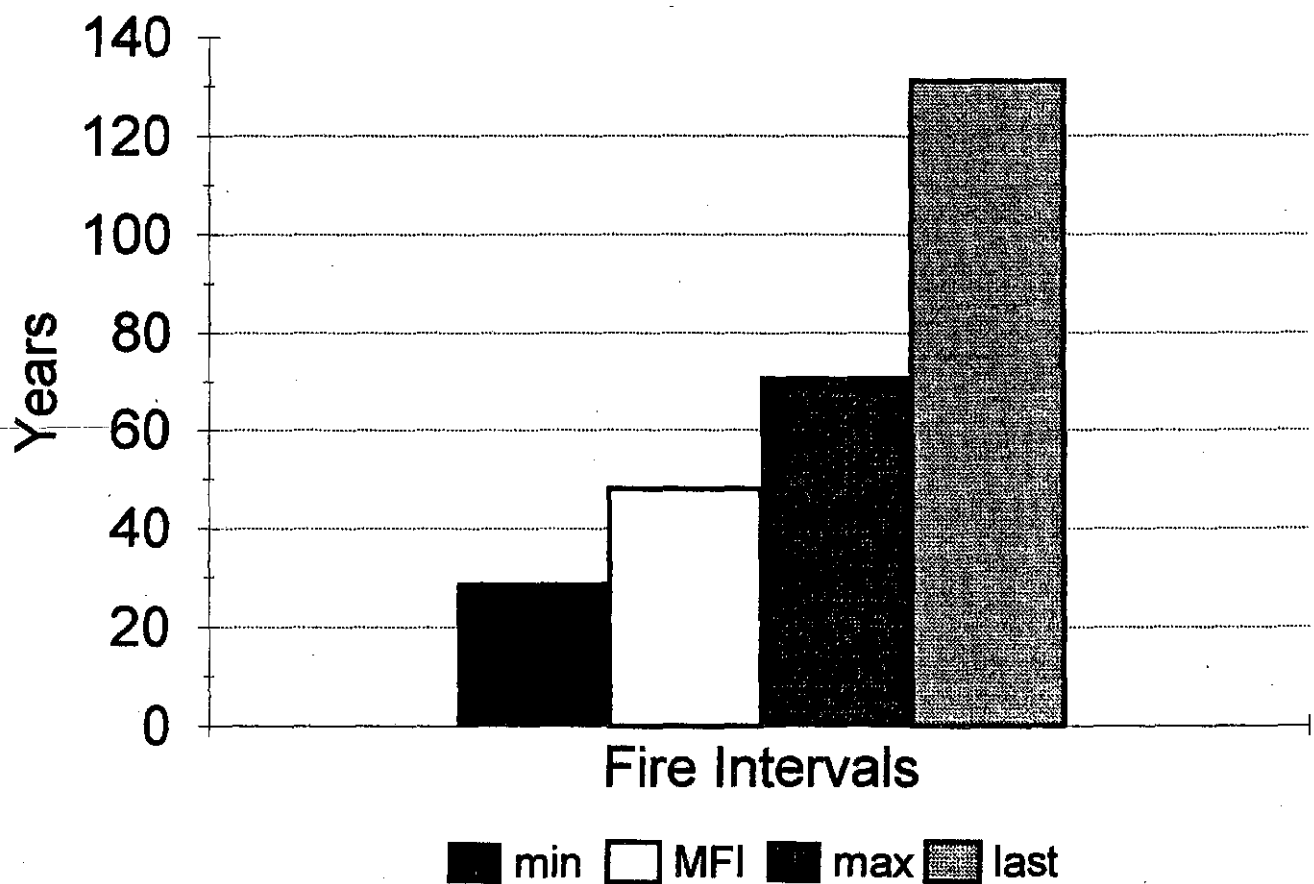
3. A=subalpine fir P=spruce; habitat type acronyms follow Pfister et al. (1977).

4. Master Fire Chronology.

5. Mean Fire Interval.

6. As of 1996.

Fig. 6. Stand Fire Intervals,
Mixed Severity Fire Regime



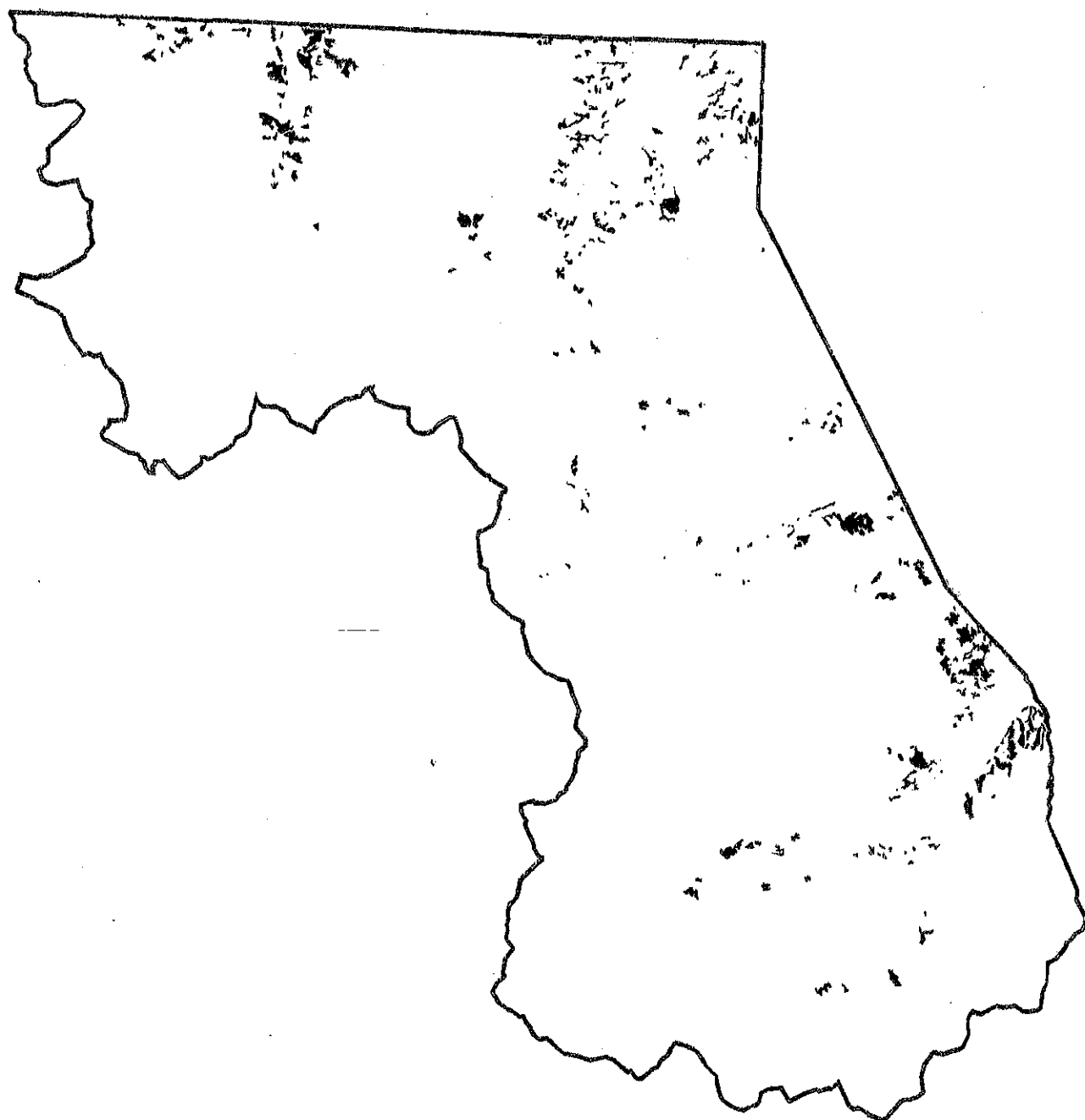


Fig. 7

Single age stands
■ Multi age stands

Single vs. Multi-Aged Stands

Scale 1:270,000

Data also were obtained from 37 moist conifer stands, which represent the bulk of the subalpine forest mosaic (table 2, fig. 7). Typically in mountain canyons, such stands are dominated by a single age class of fire-regenerated lodgepole pine and/or whitebark pine, or by uneven-aged spruce and subalpine fir. These stand structures suggest a primarily stand replacement fire regime (Arno 1980, Barrett et al. 1991, Brown et al. 1994, Agee 1993, Quigley et al. 1996). In the previous east-side study areas, stands near the mountain front often had mean replacement intervals that were less than 100 years long—only half as long as those for most interior canyon stands. The former are among the shortest intervals documented for stand replacing fires anywhere in western North America (Arno 1980, Kilgore 1981, Agee 1993, Quigley et al. 1996).

Although interior canyons now contain some of the oldest stands in the study area (fig. 4), the fire frequency sampling revealed no such differences by stand location. Actual fire intervals varied widely throughout the study area, from about 30 to 250 years long. Twelve stands near the mountain front yielded a multiple site average fire interval (MAFI; Barrett and Arno 1988) of 143 years for stand replacing fires, versus 135 years based on 25 interior canyon stands. For all 37 stands, therefore, MAFI during the pre-fire suppression era was 138 years. By comparison, the current fire interval for all stands averages 158 years (fig. 8). This result suggests that many stands were already relatively old at the beginning of the fire exclusion period. However, most stand fire intervals today are still within the presettlement range.

Several factors help explain why the above results differ from those obtained in the previous east-side study areas. First, because the Hudson Bay study area is from two to three times larger, the database might simply provide more comprehensive information on past

Table 2. Fire frequency data from 37 representative stands in the stand replacement fire regime.

Plot No ¹	Cov. Type ²	Hab. Type ³	Asp	Elev. (m)	MFC ⁴	No. Fires	Intvl. Range (yr) ⁵	MFI ⁶ (yr)	Last Fire ⁷ (yr)
1	WB-SF	A/Mefe	W	1829	1732-1844	2	112	-	152
2	WB-LP	A/Xete	SW	1920	1765-1844	2	79	-	152
3	DF-SF	A/Clun	SW	1603	1765	1	171+	-	231
5	DF-SF	A/Clun	SE	1515	1732	1	204+	-	264
17	DF-LP	A/Clun	S	1481	1488-1765	3	33-244	139	231
18	LP	A/Xete	SW	1494	1765-1891	2	126	-	105
65	DF-LP	A/Clun	N	1469	1732-1910	2	178	-	86
72	LP	A/Xete	NW	1463	1751	1	185+	-	245
77	SF-LP	A/Clun	W	1512	1658-1751	2	93	-	245
90	LP-DF	A/Clun	N	1475	1774-1936	2	162	-	60
101	LP-WB	A/Xete	N	1890	1732	1	204+	-	264
102	LP	A/Vagl	N	1744	1732-1921	3	62-127	95	75
104	LP	A/Xete	S	1853	1794	1	142+	-	202
105	WB	A/Mefe	W	1890	1680-1936	2	256	-	60
106	WB-LP	A/Xete	S	1829	1633-1936	3	92-211	152	60
109	LP-WB	A/Xete	S	1951	1732-1910	2	178	-	86
112	LP	A/Clun	W	1615	1855	1	81+	-	141
122	WB	A/Xete	W	1859	1633-1855	2	222	-	141
126	LP	A/Clun	E	1658	1732-1859	2	127	-	137
130	LP	A/Vasc	NE	1768	1692-1859	2	167	-	137
137	LP	A/Vaca	NW	1417	1761-1889	2	128	-	107
153	LP	A/Clun	NE	1451	1761-1859	2	98	-	137
156	SF-LP	A/Clun	E	1433	1794-1859	2	65	-	137
161	LP	A/Xete	E	1487	1761	1	175+	-	235

Table 2 (cont.)

Plot No ¹	Cov. Type ²	Hab. Type ³	Asp	Elev. (m)	MFC ⁴	No. Fires	Intvl. Range (yr) ⁵	MFI ⁶ (yr)	Last Fire ⁷ (yr)
162	SF	P/Clun	E	1494	1761-1834	2	73	-	162
169	LP	A/Xete	SW	1768	1794	1	142+	-	202
170	LP	A/Xete	SW	1829	1761-1794	2	33	-	202
173	LP-WB	A/Xete	SW	1847	1587-1732	2	145	-	264
177	LP	A/Clun	NE	1317	1744-1889	2	145	-	107
178	DF-SF	A/Clun	NE	1323	1744	1	192+	-	252
184	SF	P/Clun	N	1280	1794-1889	2	95	-	107
190	DF-SF	A/Clun	W	1356	1667-1744	2	77	-	252
194	DF-SF	A/Clun	SW	1463	1761	1	175+	-	235
201	DF	A/Clun	NE	1311	1761-1889	2	128	-	107
203	LP	A/Clun	E	1311	1761-1844	2	83	-	152
210	DF-LP	A/Clun	N	1366	1726-1935	2	209	-	61
212	LP-DF	A/Clun	S	1372	1844-1935	2	91	-	61
Range: 1280-1951					1488-1936	1-3	33-244	95-152	61-264
Mean: 1585					-	-	138^h	129	158

1. Locations on stand age class map (on file, GNP Research).

2. LP=lodgepole pine DF=Douglas-fir SF=spruce-fir WB=whitebark pine L=western larch

3. A=subalpine fir P=spruce; habitat type acronyms follow Pfister et al. (1977).

4. Master Fire Chronology.

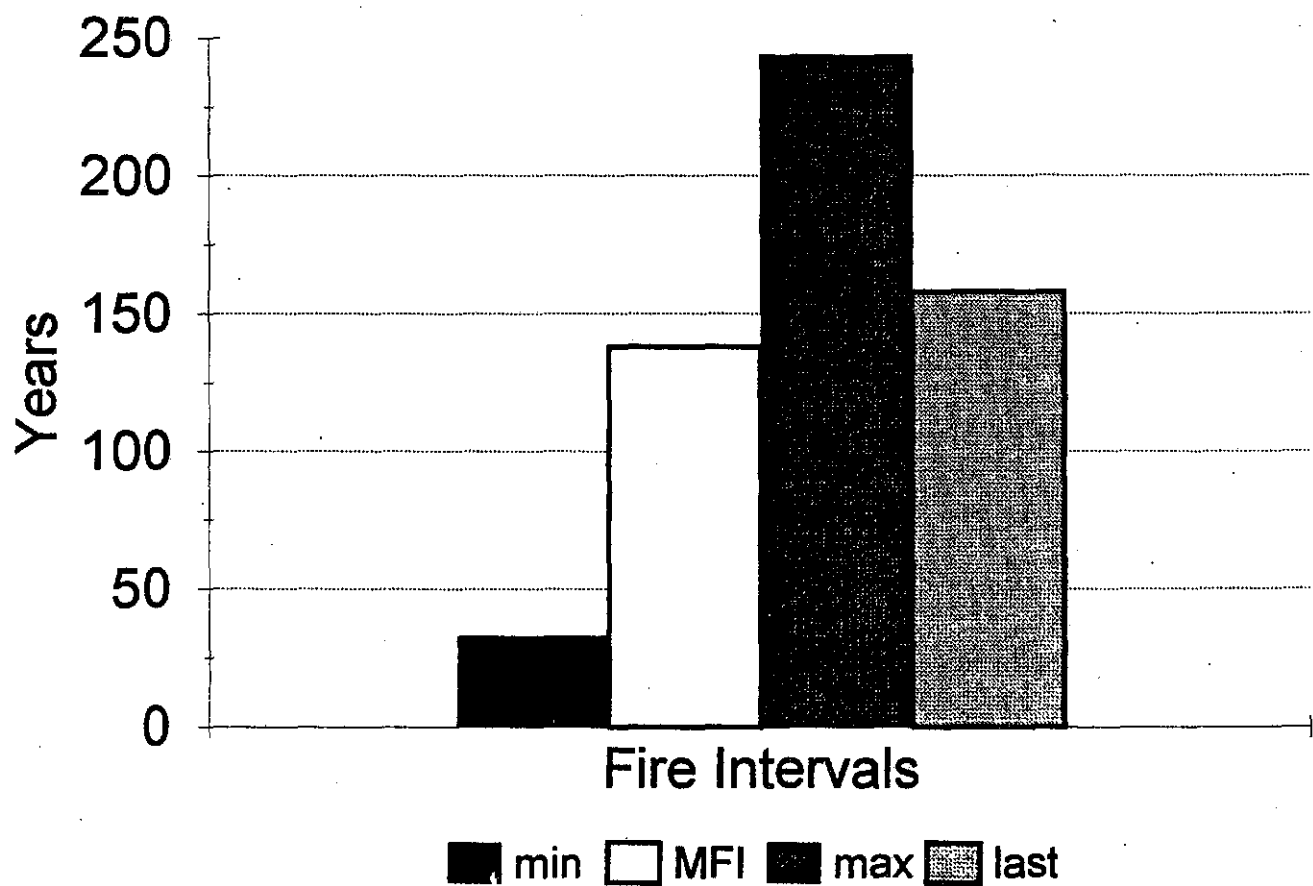
5. "+" denotes interval as of 1936 (pre-fire exclusion period).

6. Mean Fire Interval.

7. As of 1996.

h. Multiple site average fire interval (MAFI)(Barrett and Arno 1988).

Fig. 8. Stand Fire Intervals,
Stand Replacement Fire Regime



variability. However, the previous study areas contain proportionately more terrain on the mountain front, thus a wider variety of fuels more highly exposed to wind and to fires originating off-site. The earlier study areas also may have experienced more human caused ignitions, because these areas contain several major travel routes (i.e., Marias Pass, South Kootenay Pass, Akimina Pass). In fact, early forest surveyor H.B. Ayres noted that Indians and others had caused many fires in the Marias Pass trail corridor (Ayres 1900, 1901), and his photographs of the foothills near present-day East Glacier show much less forested terrain than at present (Ayres 1901).

Stands in the upper timberline zone occasionally had fire scar evidence, but yielded no usable long-term data. However, representative data were obtained in the previous east-side study areas (Barrett 1993, Barrett 1996). In GNP's Missouri River drainage, fire scars in five whitebark pine-dominated stands indicated that individual fire intervals ranged from 36 to 136 years long, and one site had an 86-year MFI. Many nearby unscarred pines also lived for 600 years or more before succumbing to blister rust and pine beetles, suggesting potentially long site fire intervals. Indeed, "stand" fire frequency has only limited meaning, given the often highly disjunct tree spacing on southerly aspects (Fischer and Clayton 1983).

Samples were also obtained from alpine larch-dominated stands on moist northerly aspects. Previously, the alpine larch cover type was thought to experience primarily long-interval stand replacing fires (Brown et al. 1994). However, evidence of short to moderately long fire intervals was found in WLNP stands (Barrett 1996), where individual larches have persisted for more than one thousand years (Luckman et al. 1993). Mature trees commonly had from one to five scars caused by mixed severity fires, particularly where underlain by carpets of

wood-rush (*Luzula hitchcockii*). Fire intervals in five sample stands ranged widely in length, from about 10 to 160 years, while the stand MFIs ranged from 46 to 90 years long. A lack of data from alpine larch stands elsewhere in this species' range makes it impossible to address which fire regimes were prevalent before 1900. Overall, however, the samples from both whitebark- and alpine larch stands verify that stand fire intervals and severities can display extreme variation along upper timberline (Morgan et al. 1994).

DISCUSSION

Ecological Implications. The fire history data should help dispel misconceptions about fire's historic role on the east slope of the Continental Divide. Understandably, infrequent lightning and the lack of fires since 1936 has fostered the impression that fires have always been uncommon. However, presettlement fires apparently were even more frequent than on the park's west side (Barrett et al. 1991) and were a primary force controlling vegetative succession and landscape diversity. Many factors have interacted to produce the east-side's impressive fire history. First, the intersecting coniferous forests, herbaceous communities, and aspen groves on the east side produce a complex mix of area fuels (Lynch 1955, Arno 1979). Weather can also be highly variable at the confluence of the Pacific Maritime- and Continental climatic regimes (Finklin 1986). Extreme fire weather, in conjunction with steep topography, diminishes the influence of aspect, elevation, and fuels on fire severity and interval length. Frequent strong winds also attain a long fetch through glacial troughs and across prairies, influencing area fire regimes by: 1) contributing to dead fuel loading (e.g., from blowdowns and red-belt winter kill [Habeck 1970, Arno 1979, Finklin 1986, Arno and Hoff 1989]), 2) desiccating all fuels during

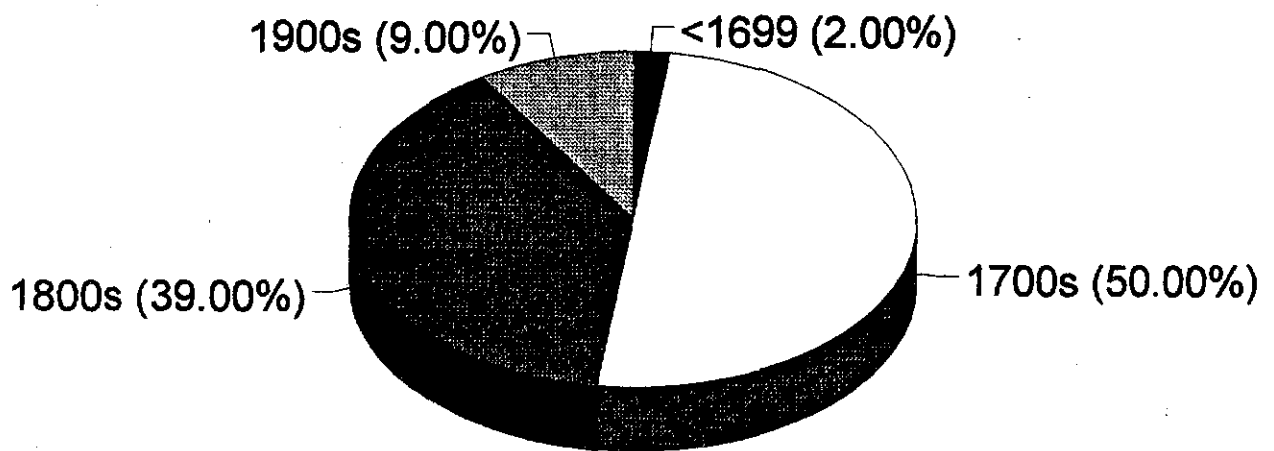
the summer forest fire season and throughout much of the year in grasslands (Finklin 1986), 3) stunting tree growth, thereby raising canopy-scorch potential, and 4) accelerating fire spread (Romme and Despain 1989, USDA Forest Service 1989). The area's steep topography also enhances fuel preheating during fires (Lotan et al. 1985). Sampling in all three east-side study areas yielded no appreciable differences in stand replacement frequency by elevational gradient, or by aspect type (table 2). These data, and the widely varying fire intervals, support the interpretation that occasional extreme fire weather can promote stand replacement burning irrespective of stand age or terrain shape (Brown 1975, Johnson and Wowchuck 1993, Morgan et al. 1994). In fact, the stand replacement intervals for most east-side stands apparently were substantially shorter, and displayed wider variation, than in the generally more productive stands on GNP's west side. For example, fire intervals averaged about 200 years for stands in the Middle Fork and McDonald Creek drainages (Barrett et al. 1991).

Some researchers (Johnson and Fryer 1987, Johnson and Larsen 1991, Johnson and Wowchuck 1993) have not recognized the diverse fire regimes that occur in this portion of the Northern Rockies (Agee 1993, Quigley et al. 1996), and thus may have unintentionally biased their results by analyzing only the stand replacement fire regime. Further, the researchers may have overemphasized climate's role in fire history (Finney 1995) while simultaneously discounting humans as a potential cause and suppressor of many fires. For instance, these researchers argue that organized fire suppression has had only minimal influence on stand replacement fire frequency (Johnson and Fryer 1987, Johnson and Larsen 1991, Johnson and Wowchuck 1993; Johnson et al. 1990, Masters 1990). In their view, climate is felt to be the primary influence by promoting fires during extreme weather, producing most of the burned area

in a given large ecosystem. Wind-driven wildfires are virtually impossible to control (Johnson and Fryer 1987, USDA Forest Service 1989, Romme and Despain 1989, Johnson et al. 1990). However, successfully extinguishing most other ignitions--such as early-season "sleepers" that later might have burned substantial acreage--could markedly influence the composition of today's mosaic. Extinguishing many small, low-severity fires would also profoundly affect succession in grasslands and other dry community types (discussed below). Countless incidents of extreme summer fire weather have occurred in Waterton-Glacier over the past 60 years, for example, fast-moving cold fronts that could easily have activated any small fires in the study area.

An analysis of the age class data supports the interpretation that fire suppression has been very effective. Specifically, the study area age class mosaic is now heavily skewed toward older stands (figs. 4, 9; Appendix). Ninety-one percent of the seral stands are between 100 and 350 years old, including 52 percent older than 200 years. Statistically, this skewed distribution is contrary to what would be expected in a large area with frequent stand replacing fires (Johnson and VanWagner 1985, Brown et al. 1994, Johnson and Gutsell 1994). Without a major climate change or effective fire suppression, recurrent stand replacing fires would skew the age class distribution toward young- to mid-age stands. While no clear relationship between macroclimate and fire occurrence has been established (Agee 1993, Barrett et al. [in press]), a climatically induced change in fire frequency likely can be ruled out. Studies show that severe single-year droughts occurred in the Northwest at least 10 times between 1940 and 1995, and occurred in every decade (Karl and Koscielny 1982, Graumlich 1987, Meko et al. 1993).

**Fig. 9. Percent of Study Area
Age Classes by Century**



Formal attempts at fire exclusion began even before GNP's inception in 1910, but early efforts were largely ineffective throughout the region (Wellner 1970). By 1940, however, increasingly efficient technology began to produce a measurable decline in fire frequency in many areas of the Northwest (Wellner 1970, Arno 1980, Quigley et al. 1996, Barrett et al. [in press]). This interpretation is well supported by the data from all three east-side study areas--together totaling some 201,000 contiguous hectares. For example, based on pre-1940 fire frequency in the Hudson Bay drainage, and assuming a similar macroclimate since 1940 (Finklin 1986, Balling et al. 1992), as many as ten forest fires would have occurred during the last six decades. Many fires also would have occurred in the area's dry grassland- and aspen ecosystems without efficient fire suppression.

The study area vegetation mosaic thus reflects the effects of pre-1940 fires and sixty years of fire exclusion. Results from the stand mapping suggest that small to moderate size fires were common in the past, and that fire spread was often highly disjunct even during major events. Based on the 40 percent of the seral mosaic with fire-specific labels (e.g., "1889" class), today's maximum stand size is only about 250 hectares. Moreover, the mean sizes of single- and multi-age stands were just 16 hectares and six hectares, respectively. The same pattern presumably applies for the remaining 60 percent of the stands with only fire-period labeling (e.g., "1765-1794"), now too commingled for precise mapping. Today's coniferous forest mosaic is still complex, largely because of the highly variable terrain and land cover types (figs. 2, 10). Without fire exclusion, the fire generated portion would be substantially more diverse.

Most ignitions during this century have been caused by humans, largely in the lower elevations. Lightning ignitions evidently are infrequent on the east side because most strikes

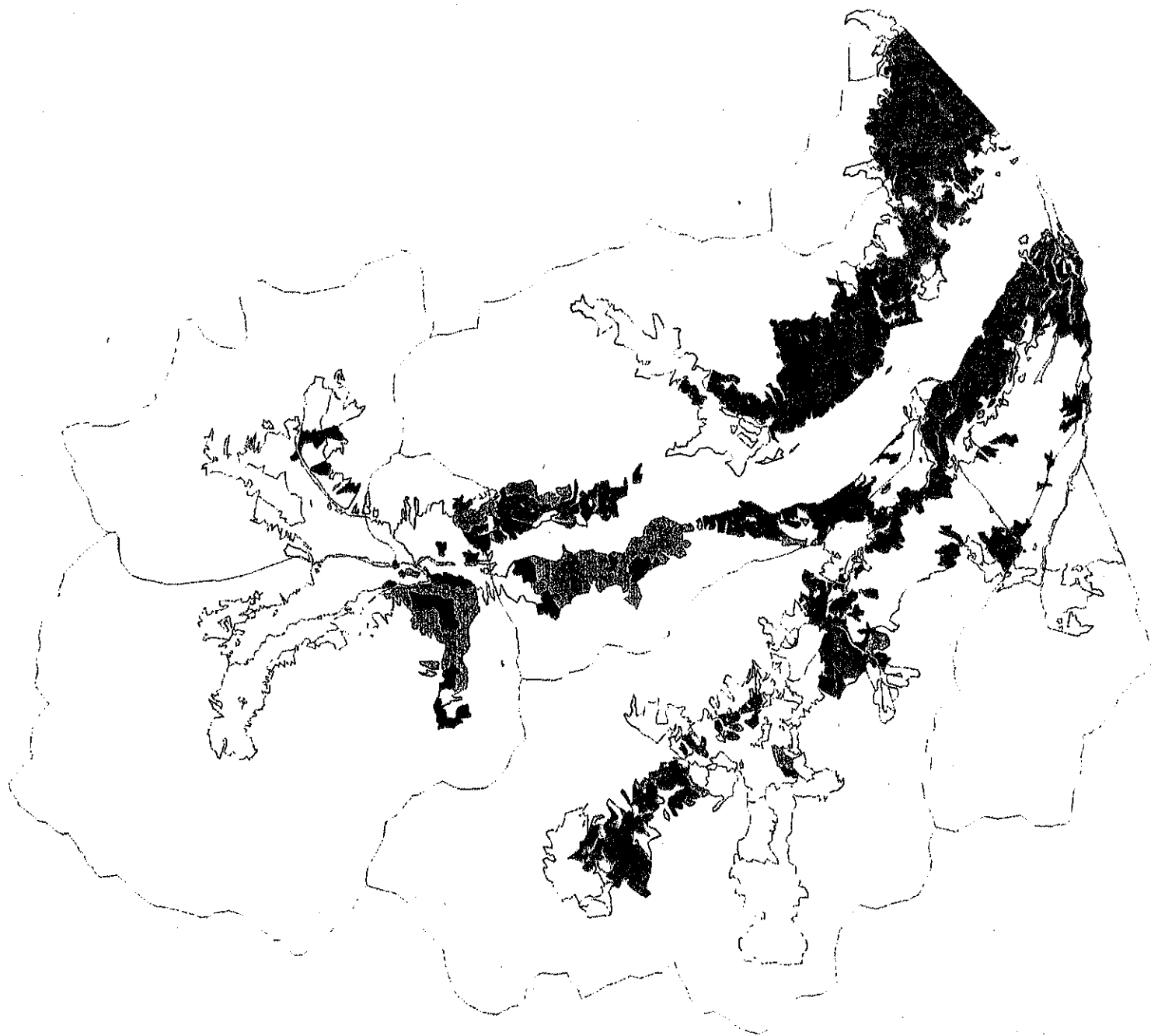


Fig. 10

Fire Age Class Mosaic - St Mary Area

Scale 1:135,000

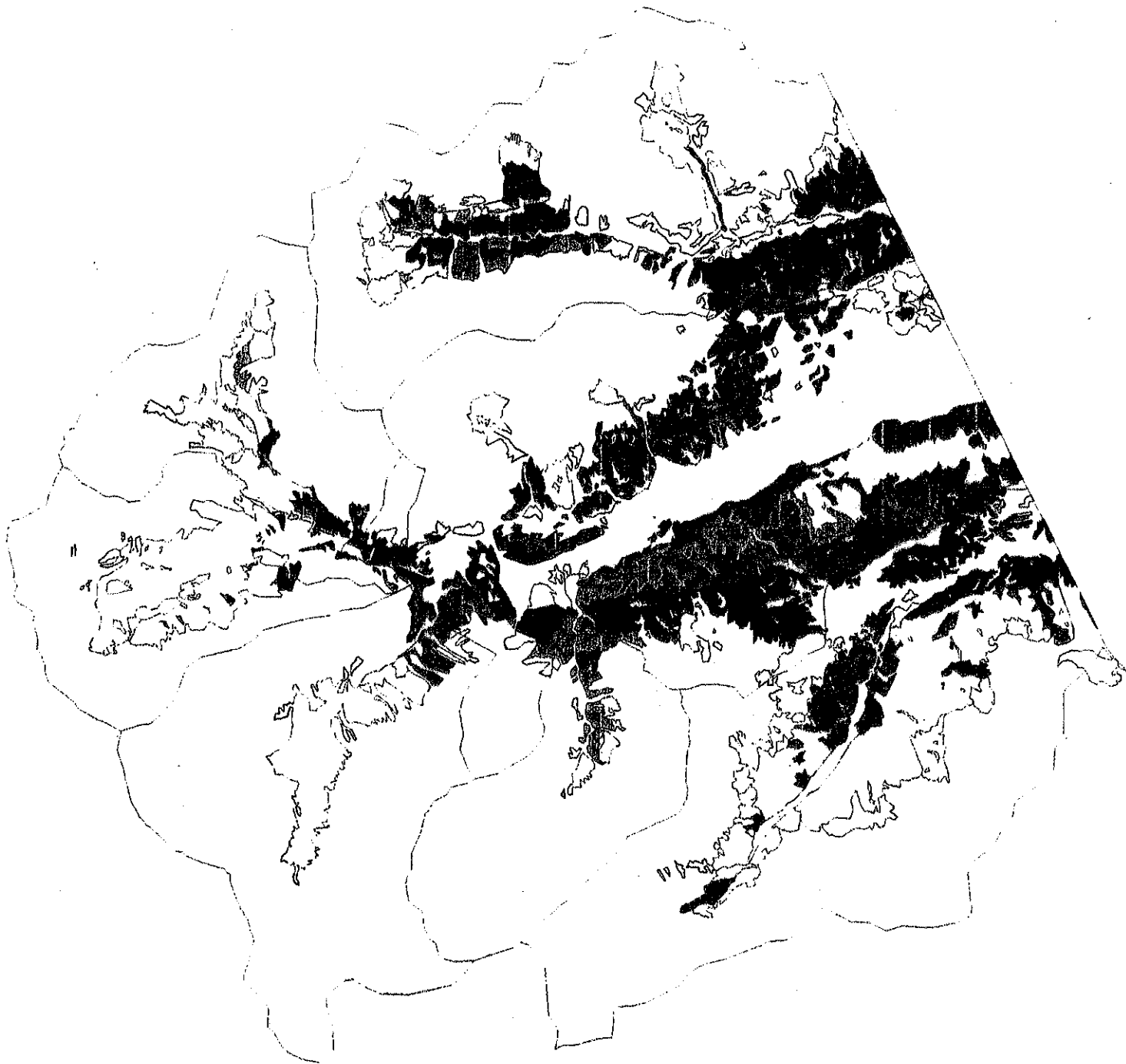


Fig. 10 (cont.)

Fire Age Class Mosaic - Many Glacier

Scale 1:110,000

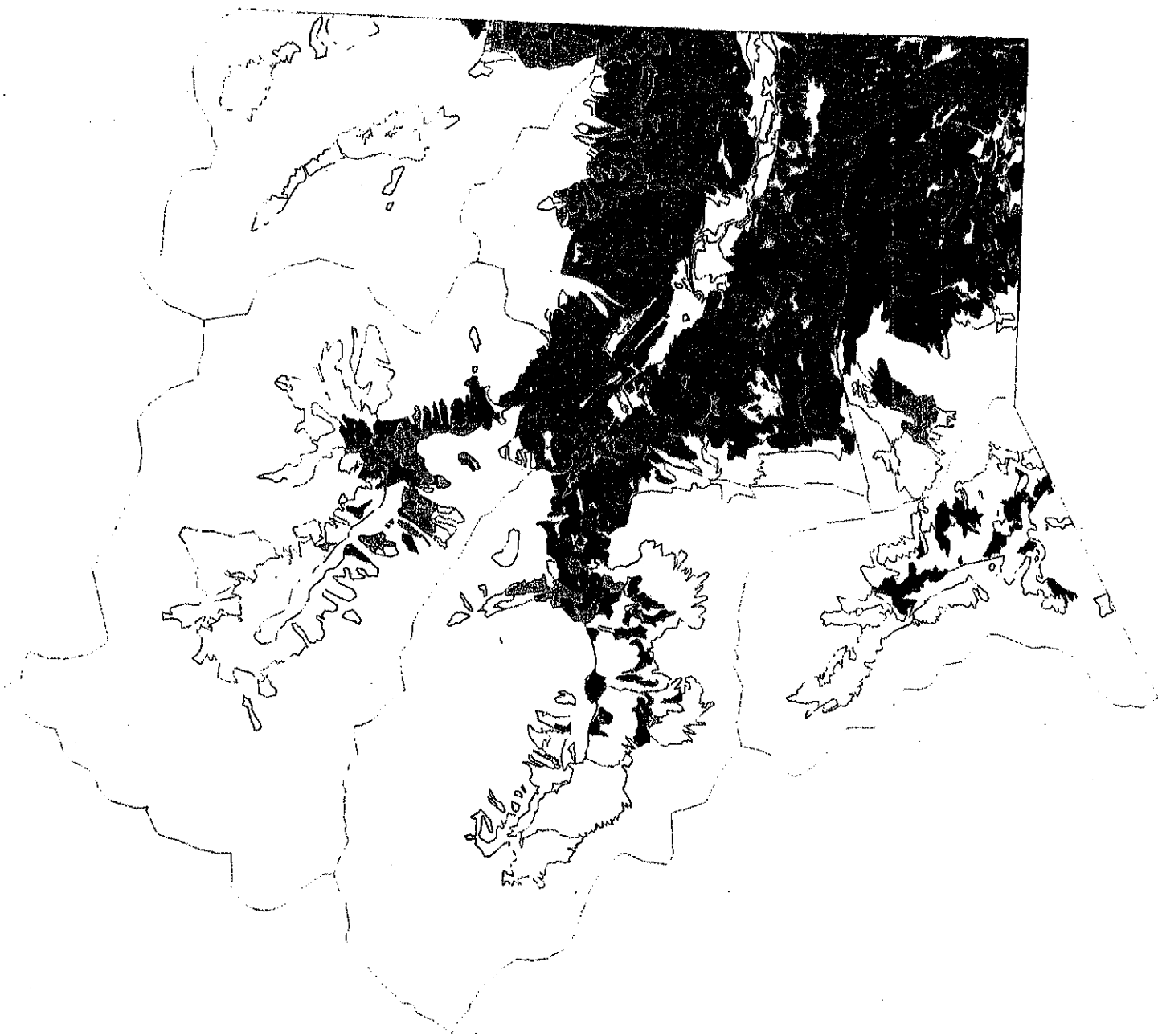


Fig. 10 (cont.)

Fire Age Class Mosaic - Belly River

Scale 1:120,000

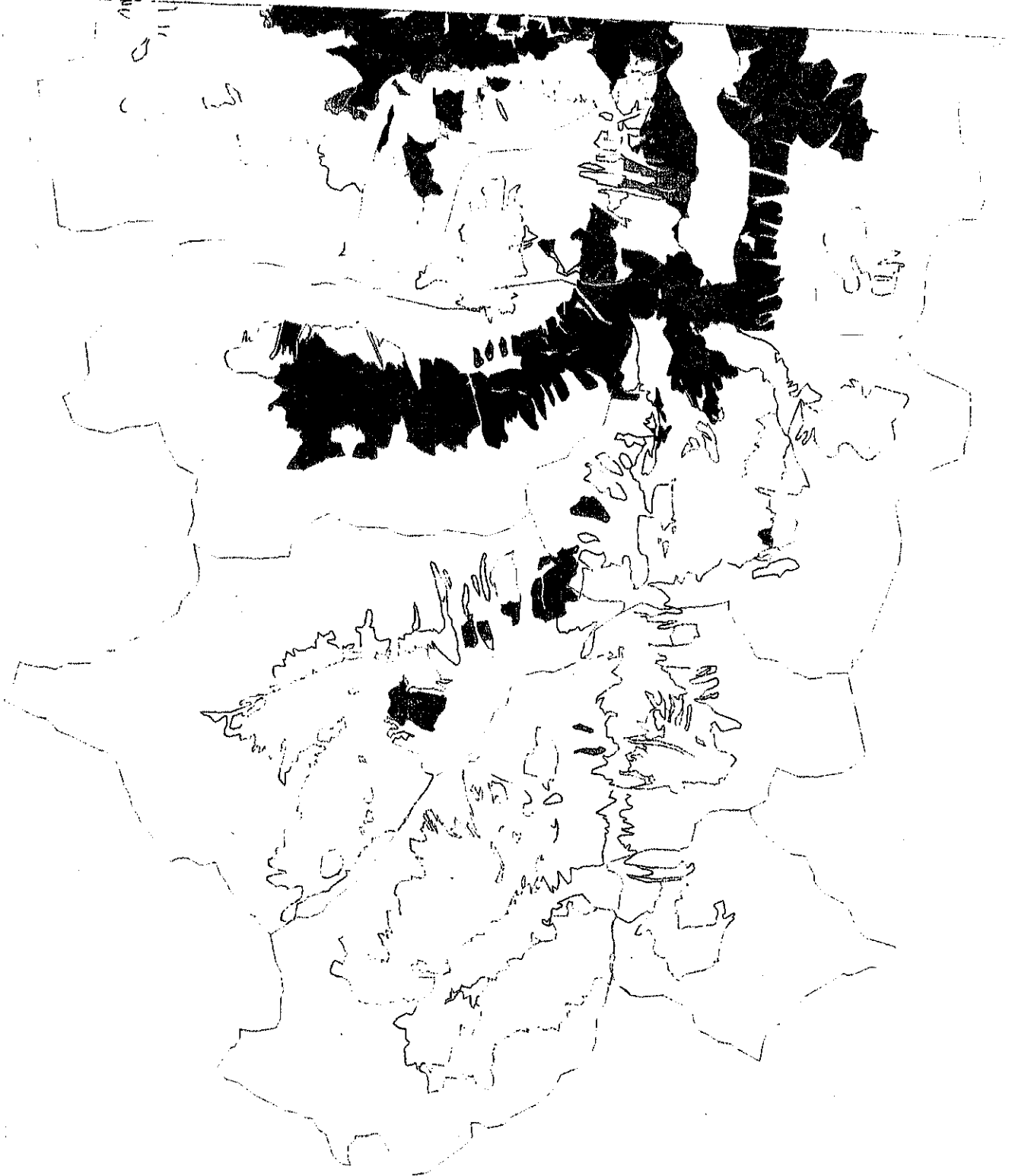


Fig. 10 (cont.)

Fire Age Class Mosaic - Waterton River

Scale 1:100,000

occur in alpine rocklands (Finklin 1986). In WLNP, for example, lightning caused less than 25 percent of all recorded ignitions between 1930 and 1995, largely in mid- to upper elevation terrain (fire atlas on file, WLNP). Detected lightning ignitions have averaged only one every six or seven years in both WLNP and the Missouri River drainage, proportionally similar to the ignition rate in the larger Hudson Bay study area (fire atlas on file, WLNP; O'Brien 1969). From these results, lightning alone may have been incapable of producing the robust fire history found in all three east-side study areas.

Humans also may have caused most of the pre-1900 fires. Archaeological sites in WLNP suggest a long history of aboriginal occupation (unpub. data on file, WLNP) and Indians throughout the region commonly ignited fires in grasslands and adjacent dry forests (Barrett and Arno 1982, Gruell 1985, Barrett and Arno [in prep]). Purposeful and accidental fires served many purposes, such as influencing game movements and rejuvenating forage, game drives, clearing campsites and trails, communication, warfare, and entertainment. Coincidentally, a Blackfeet Indian recently told me about so-called "horseback lightning," whereby his ancestors regularly burned grasslands along the mountain front using transported embers. Scant written records do not reveal how many fires may have been caused by settlers, but much of the area was bypassed because the rugged terrain presented few viable economic opportunities. Rather than causing fires locally, settlement in general may have begun to reduce area fire frequency even before 1900. That is, traditional aboriginal cultures had declined by the late 1800s, and heavy livestock grazing had begun to reduce fuels in many areas. Both factors contributed to reduced fire frequency on prairies and adjacent foothills (Gruell 1985, Arno and Gruell 1986).

The case for frequent human-caused fires during the presettlement period seems well

supported by the fire history data. First, area fire frequency remained consistently high throughout both dry- and moist macroclimatic periods in the chronology. However, less than one-third of the fires in the chronology were major events, perhaps indicative of infrequent lightning fires. Many other fires were small patchy burns near lower timberline, perhaps of human origin. Unlike in moist subalpine forests, dry valley-edge stands often have a herbaceous understory that becomes combustible nearly every spring and fall irrespective of macroclimatic trends. However, the current fire interval in 15 such stands averages 131 years (table 1), which shows declining fire frequency by the late 1800s despite increasing drought.

The fire history data thus raise concerns about the effects of fire exclusion at both the landscape- and stand scales. From a landscape perspective, the forest mosaic has been aging more uniformly, thus becoming less diverse spatially and compositionally (Romme and Knight 1982). Early photographs (Ayres 1901, Gruell 1983) show that many areas along the Rocky Mountain Front previously had a greater mix of post-fire successional stages, including much more unforested terrain (fig. 11). Without repeated fires, forest coverage has increased by 50 percent or more in many areas. Elements of the subalpine forest in the park's interior have also changed, if more subtly. Due in part to fire's absence since 1936, stand decadence caused by insects, blister rust (*Chronartium ribicola*), root rots, and subsequent windfall is widespread in all three east-side study areas. By prolonging the survival of most pine age classes in this century, fire exclusion also exacerbated the unusually large pine beetle (*Dendroctonus ponderosae*) epidemic in northern Waterton-Glacier during the 1980s (Armour 1982, Barrett et al. 1991). Presumably, altered landscape succession can also promote more-extensive wildfires (Agee 1993), such as the 15,000 ha. Red Bench Fire on the park's west side in 1988 (Barrett et al.



Plate 17a (July 6, 1921) Fire Group 1: Dry limber pine. Elevation 6,200 ft (1 890 m)
 Camera faces east from a position on Two Medicine Ridge about 6 miles northeast of East Glacier, Mont. The many snags resulted from a wildfire in 1910. Scattered stumps show evidence of early timber cutting. Dark tone of open slopes reflects condition of herbaceous vegetation before curing.
 USGS photograph 1101 by W. C. Alden.



Plate 17b (September 27, 1981) 60 years later
 Conifers include whitebark pine, lodgepole pine, subalpine fir, and Douglas-fir. The dry slopes dominated by perennial grass appear unchanged. Aspen have regenerated on deeper soils (lower right) that supported conifer before the fire. Aspen stands growing in association with conifer (right in distance) regenerated following the 1910 wildfire.
 Photograph by G. E. Gruell.

Fig. 11 (cont.)



Plate 23a (1900) Fire Group 6: Moist Douglas-fir. Elevation 5,300 ft (1 616 m)

From the ridge about 5 miles west of Haystack Butte, the view is southwest across Smith Creek toward Crown Mountain on east front of Rocky Mountains, Lewis and Clark National Forest. Near slopes are in early succession following wildfire in latter 1800's that removed conifers and stimulated production of aspen, willow, chokecherry, mountain maple, and other deciduous vegetation. Stumps resulting from timber cutting and snags indicate that the pre-1900 conifer stands were less dense than current stands.

USGS photograph 665 by C. D. Walcott.



Plate 23b (September 16, 1981) 81 years later

Slopes below camera point and adjacent terrain as well as near slope are now densely covered by Douglas-fir. View was obtained by cutting screening fir and climbing one of the larger Douglas-fir about 50 yards from original camera position at top of ridge. Canopy closure has resulted in a decline in condition of deciduous species.

Photograph by G. E. Gruell.

Fig. 11 (cont.)



Plate 24a (1900) Fire Group 6: Moist Douglas-fir. Elevation 5,300 ft (1 616 m)

Looking west-northwest toward Cyanide Mountain on the Wood Canyon drainage, Rocky Mountain Front, from a point approximately 50 yards below previous plate. Influence of wildfire in latter 1800's is indicated on left side of photo and on Cyanide Mountain in distance by presence of snags and early successional vegetation including aspen. Grassy slopes on right are apparently too dry to support conifers. USGS photograph 666 by C. D. Walcott.

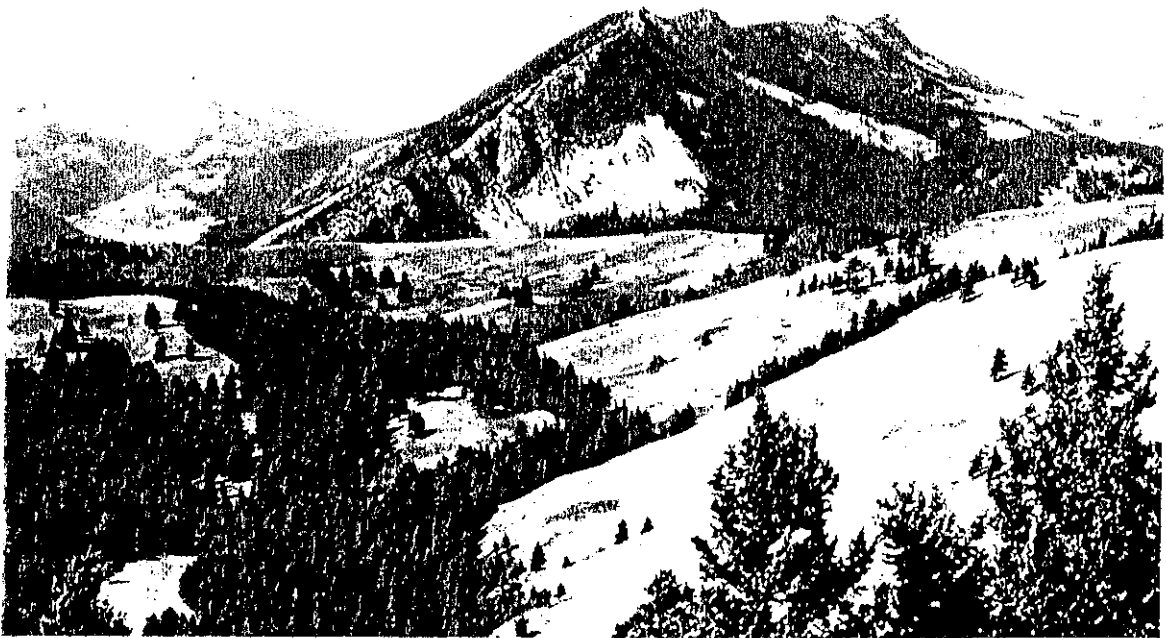


Plate 24b (September 16, 1981) 81 years later

Camera was moved about 100 yards down slope from original position to avoid trees that screened view. Closure of Douglas-fir canopy (lower left) has resulted in deterioration of aspen and associated early successional plants. Proliferation of conifers is apparent in distance.

Photograph by G. E. Gruell.

1991). In fact, the east side exhibits widespread mortality in subalpine stands with possibly interrupted fire cycles, for example, in the upper St. Mary- and Belly River drainages. Large forest fires would not be totally unprecedented, however. Early photographs show that extensive burning had occurred in the lower Belly River drainage shortly before the International Boundary Survey in 1874 (on file, WLNP).

Of interest to fire managers, the data suggest that fires often occurred in the same year or short period on both sides of the Continental Divide (e.g., ca. 1667, 1683, 1735, 1761, 1844, 1889, 1910, 1919) (Barrett et al. 1991, Barrett 1993, Barrett 1996). For example, the GNP fire atlas and written records (O'Brien 1969, McLaughlin 1978) indicate that large wind-driven fires in 1910 and 1936 readily crossed the Continental Divide near Firebrand- and Swiftcurrent Passes. A vivid example is the 1936 Heaven's Peak Fire, which burned 1200 ha. in the upper McDonald Creek drainage before crossing the Divide and burning 2350 ha. in the Swiftcurrent Valley:

"At 8:45 on the evening of September first . . . as my party of hikers topped the rise of ground separating Swiftcurrent Lake from Lake Josephine an occasional flake of ash settled . . . As we emerged on the margin of Grinnell Lake, the ash was raining down . . . The wind was blowing strongly from the west bearing more ash and branches, still glowing as they hissed into the water . . . I pointed to the precipitous Garden Wall rising four thousand feet from the valley floor and said "there's no way the fire can cross over that wall." I hoped I had sounded convincing . . . Dusk was deepening and we became aware of a glow in the sky near the summit of Swiftcurrent Pass . . . Suddenly, to our utter amazement, a tree near the summit on the east side of the pass caught fire and blazed against the night sky like a fiery cross . . . All at once a tree lower down caught and the entire flank of Mt. Wilbur became a racing sheet of flame . . . " (McLaughlin 1978: 8-10).

This ranger's observation illustrates one of the challenges faced by park managers. Given the east side's propensity for high winds, even small "goat rock" fires can quickly develop into

unmanageable wildfires.

Besides landscape concerns, the data also yield important implications for stand-scale management. The most frequently burned communities should be of special concern to managers. For example, although multi-age stands comprise just 10 percent of the coniferous forest, dry conifer stands, aspen groves, and herbaceous communities together total some fifteen thousand contiguous hectares. This totals nearly half as much land area as occupied by conifer stands with a predominantly stand replacement fire regime. In addition to disrupted fire cycles, succession in dry low-elevation communities has also been seriously impacted. For instance, lack of mixed severity fires has promoted overstocking and closed canopies in many old multi-age stands. Also, many of the younger single-age stands would now be multi-aged if fire exclusion had not occurred. Because of these structural changes, most low-elevation conifer stands likely have shifted into the stand replacement regime (Arno and Gruell 1983, Arno and Gruell 1986, Agee 1993, Brown et al. 1994, Quigley et al. 1996). Examples of such stands are readily visible today near Two Dog Flats and Lower Red Eagle Creek, along lower Swiftcurrent- and Lee Ridges, and bordering Upper Waterton Lake. Fire's absence has also caused many aspen groves to decline in vigor, and some meadows have been successfully invaded by trees (Habeck 1970).

For areas with a presettlement stand replacement regime, most stand fire intervals are still within the range of natural variation. However, landscape-level fire exclusion, concurrent with the recent heavy mortality in whitebark pine, poses a significant threat to that species' future (Arno 1980, Arno and Hoff 1989, Keane and Arno 1993, Keane et al. 1990, Kendall and Arno 1990, Tomback et al. 1990, Keane and Morgan 1994, Morgan et al. 1994). Over the past

50 to 100 years in the Northwest, the spruce-fir cover type has increased by 40 percent or more because of fire exclusion in tandem with blister rust- and mountain pine beetle epidemics (Arno 1980). Previously, fires on many whitebark pine-dominated sites allowed that species a competitive advantage over shade tolerant species, because the seral pines regenerated more rapidly in fire-caused openings (Tomback et al. 1990). However, due to the rapidly declining seed source, even large fires in the future might fail to reestablish dominance by seral whitebark pine.

Along upper timberline, most fires were patchy and highly localized (Arno 1980, Arno and Hoff 1989, Morgan et al. 1994). The east-side sampling supports this interpretation, because few high elevation fires were also represented on stand origin maps (Barrett 1993, Barrett 1996). Despite their small size, however, the fires were important for stand thinning and regeneration (Arno 1980, Arno and Hoff 1989, Morgan et al. 1994). Many trees also persisted for centuries because fire spread was limited by the frequently sparse and discontinuous fuels, and because fires consumed competing vegetation. The highly variable pre-1900 fire frequency suggests that most stand fire intervals are still within the range of natural variability. However, many stands contain dense fir understories interspersed with whitebark pine snags and logs, or, alpine larch thickets in reproduction glades (Arno and Hoff 1989, Arno 1990). These fuels can increase fire potential, especially near the continuous subalpine forest. Conversely, on droughty upper timberline sites, climax whitebark pine was often the only tree present and post-fire regeneration typically was very slow. Without a viable pine seed source, many such sites will likely revert to persistent herbaceous- or shrub-dominated communities, even with prescribed fires (Keane et al. 1990).

Management Implications. Fire history information can help guide managers in attempting to restore fire to a semblance of its natural role (Kilgore 1981, Arno and Brown 1989, Mutch 1994, Mutch et al. 1994). For example, the data show that grasslands, aspen groves, and multi-age conifer stands near lower timberline are among the most seriously impacted ecosystems to date. Moreover, the risk of human caused ignitions continues to grow in these increasingly heavily visited areas. To reduce fire hazards and promote more natural succession, therefore, these low elevation ecosystems represent a logical focal point for manager-ignited fires during spring and fall. Such a policy would be particularly justifiable, because past lightning fires may have been insufficient for perpetuating those presettlement fire cycles.

Fire exclusion has also affected upper timberline stands, if less predictably. Still, suppression of all high-elevation fires is inadvisable because even tiny fires helped thin understories and prepare seedbeds for tree regeneration. Since lightning ignitions are comparatively infrequent, manager-ignited fires during low-risk periods might be the most effective way to restore fire to these communities. Alternatively, a more controversial fuel reduction measure would be to use chainsaws to thin the understories of any particularly important whitebark pine groves (thinning could also be accomplished before burning).

Presettlement fire cycles (Romme 1980) can provide useful data for prescribed fire planning. By enabling estimates of the mean annual area burned per cover type, fire cycles can help managers identify and prioritize areas for treatment (Quigley et al. 1996). However, mapping and reliably quantifying past fire occurrence in grasslands is infeasible, for many reasons. Fire scarred conifers provide the only evidence of long-term fire history in this locale, but these MFIs might have been considerably longer than those for adjacent grassland sites.

Tree fire scars also are scarce in these ecotones because rapidly spreading grass fires often fail to scar conifers (Arno 1976) and can easily kill thin-barked aspens (Jones and DeByle 1985). Also, grass fires sometimes occurred when adjacent forest fuels were too moist to burn, such as in early spring. Grassland fire intervals may have varied considerably, for example, Indians may have burned some areas annually, whereas any heavily grazed sites would not have burned (Gruell 1980, 1983). However, even a rough estimate of presettlement fire frequency might be useful for planning purposes. If the total of 4405 ha. occupied by low elevation grasslands is divided by a ten-year MFI, then mean annual burned area equals 441 ha. This historically based index might be useful, for example, as an annual goal for prescribed fire acreage in grasslands. The fire cycle also serves as one measure of fire exclusion, since about 26,400 ha. of grasslands might have burned over the past six decades (i.e., 441 ha. multiplied by 60 yr).

Climax aspen groves are not necessarily fire dependent, but fires helped limit their extent and distribution (Lynch 1955, Habeck 1970, Jones and DeByle 1985, Barrett 1993). Extrapolating data from dry conifer stands is the most feasible approach for estimating aspen fire cycles, because aspens are usually short lived, lack fire scars, and are difficult to age (Lynch 1955, Campbell 1981, Jones and DeByle 1985, Barrett 1993). Note that the conifer data are probably accurate for seral aspen groves in the montane forest (Barrett et al. 1991, Barrett 1993), while conservative for climax groves in grasslands. However, dividing the total of 10,284 ha. occupied by multi-age conifer- and aspen stands by a 48-year MFI (table 1) yields a mean of 215 ha. burned annually. (By cover type, presettlement fires burned an average of 63 ha. of multi-age conifer stands and 152 ha. of aspen stands per year). When this result is multiplied by the 60-year fire exclusion period to date, as many as 12,900 ha. occupied by these types might have

burned since 1936.

For the 29,603 ha. of single-age stands in the subalpine forest zone, an average stand replacement interval of 138 years (table 2) yields a mean annual area burned of 215 ha. Because fire exclusion's effectiveness is more ambiguous in the moist subalpine forest, estimating a theoretical "backlog" of potential burned hectares since 1936 may be inappropriate. Estimating fire cycles for upper timberline stands also is difficult because of the extreme variability in that forest zone. But, in summary, fires theoretically would have burned at least 40,000 hectares in the study area between 1936 and 1996, equivalent to 90 percent of the total vegetated area. That is, some meadows and dry conifer stands would have burned more than once during the fire exclusion period, while other cover types would not have burned. In reality, less than 300 hectares burned between 1936 and 1996, or less than one percent of the vegetated area.

Fire has shaped Western landscapes for the past 10,000 years, but a century of settlement activities has disrupted that crucial role (Arno 1980, Pyne 1982, Quigley et al. 1996). Even in large natural areas like Waterton-Glacier International Peace Park, many ecosystems have changed visibly from the presettlement condition. For restoration, prescribed fires might help mitigate fuel hazards and help perpetuate some of the park's fire-dependant communities. Otherwise, in view of shifting fire regimes and declining landscape diversity, it is unclear which ecosystems will retain their primeval character.

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Fig. 10. LEGEND - Fire Age Class Mosaic Mapping

- 1658 to 1692 ; single-aged stands
- 1658 to 1692 ; multi-aged stands
- 1726 to 1744 ; single-aged stands
- 1726 to 1744 ; multi-aged stands
- 1751 to 1794 ; single-aged stands
- 1751 to 1794 ; multi-aged stands
- 1834 to 1844 ; single-aged stands
- 1834 to 1844 ; multi-aged stands
- 1859 to 1891 ; single-aged stands
- 1859 to 1891 ; multi-aged stands
- 1910 to 1936 ; single-aged stands
- 1910 to 1936 ; multi-aged stands
- 1600's period regeneration (single-aged)
- 1600's period regeneration (multi-aged)
- 1700's period regeneration (single-aged)
- 1700's period regeneration (multi-aged)
- 1800's period regeneration (single-aged)
- 1800's period regeneration (multi-aged)
- 1900's period regeneration (single-aged)
- 1900's period regeneration (multi-aged)
- Primary component shows no evidence of burning (multi-aged)

Note: Green lines are watershed boundaries

APPENDIX

Study Area Master Fire Chronology.

20th Century	19th Century	18th Century	Pre-18th Century
1936			
1935			
1934			
1921			
1919			
1910			
	1891		
	1889		
	1880		
	1869		
	1866		
	1863		
	1859		
	1855		
	1844		
	1834		
		1794	
		1774	
		1765	
		1761	
		1751	
		1732	
		1726	

			1699
			1680
			1667
			1658
			1633
			1587
			1561
			1488

Area Master Fire Chronology¹: 1726-1936

Number of Fires: 23
Fire Interval Range: 1-40 yr.
Mean Fire Interval: 10 yr.
Years Since Last Fire²: 60 yr.

¹Chronology based on post-1700 mapped age classes (GIS data on file, GNP).

²As of 1996.

4/23/97 ADDENDUM

Additional information has been obtained on the study area's fire history. First, two journals helped identify specific fire years and locations. H. B. Ayres' (1900) report contains the following passage:

"The fire of 1885, starting from an Indian camp on Rose Creek, with a strong wind from the southwest, swept the whole wooded side of the ridge to the foot of St. Mary Lake, covering an area of about ten square miles in a few hours. Most of the trees were killed, only a few clumps being left here and there. Restocking has been very imperfect; small areas here and there now have an abundant growth of lodgepole pine and [Douglas-fir], but grass, willows and aspen occupy most of the old burn."

The diary of early-day ranger Frank Liebig also states that he fought a fire in that locale in 1906.¹ Field sampling initially suggested the 1889 and 1910 fires, which occurred elsewhere in the study area, but the data evidently indicate the 1885 and 1906 events. Therefore, two more fire years were added to the study area Master Fire Chronology. The estimated 25 fire years between 1726 and 1936 now yield a 9-year MFI for the pre-fire suppression period (versus 10 yr. previously reported). As well as documenting a past Indian-caused fire, Ayres' account also verifies that mixed severity fires maintained much early seral vegetation near Two Dog Flats, and illustrates the potential of wind-driven fires.

Additional data also were obtained for the fire suppression period. Annual Fire Reports (on file, GNP Fire Cache) indicate that four partially suppressed wildfires burned a total of 293 ha. in the study area, in 1945 (117 ha.), 1969 (126 ha.), 1974 (42 ha.), and 1984 (8 ha.). These fires burned primarily in 1700s regeneration, thus altering the previously reported results for study area age class composition and fire cycles. Twentieth century age classes total 11 percent of the forest mosaic (vs. 9% previously reported), 1800s classes total 39 percent, 1700s classes total 48 percent (vs. 50% previously reported), and 1600s age classes total 2 percent. Fire cycle for the 1900s to date is 873 years (vs. 1066 yr. previously reported), the 1800s fire cycle is 256 years, and the 1700s fire cycle is 208 years (vs. 200 yr. previously reported). Although the original fire history interpretations remain largely unchanged, these new data helped improve accuracy and will be used in any future publications.

¹ Guthrie, C. W. (ed.). 1995. *The First Ranger: Adventures of a Pioneer Forest Ranger. (Glacier Country 1902-1910)*. Copyright 1995 by C. W. Guthrie, Redwing Publishing, Huson MT.